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DEVELOPMENT OF HIGH RESOLUTION IMAGING DETECTORS AND OPTICS FOR X-RAY

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Final Report

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1 SR&T Achievements

Over the past SR&T funding period, we have had several successful advances in x-ray detector technology development. These include the:

1. successfully designed, built, and tested a prototype hard xray, high spatial resolution imaging detector. (The summary of results was presented in the HXI section).
2. successfully fabrication of superconducting tunnel junctions that are currently being characterized in the x-ray wavelengths for use as high spectral imaging devices. (The summary of results was presented in the STJ section).
3. investigation of passive square pore MCP's as x-ray optical elements. (The summary of results is discussed below).
4. fabrication and characterization of high spatial resolution thin film MCP readout devices. (The summary of results is discussed below).

1.1 MCP Optics

Over the past funding period we have investigating the use MCP's as soft and hard x-ray focusing devices. It has already been demonstrated that passive MCP's can be used as collecting devices for soft x-rays and that the MCP inner channel surfaces are smooth enough to reflect the soft x-rays efficiently. These devices have be used to focus x-rays with a high efficiency and good angular resolution. If they could be fabricated into a large area optical system, they have the ability to revolutionize the field of x-ray optics. We have constructed preliminary ray tracing models that are being used to determine the radius of curvature and L/D ratio to optimize such an optic. These models are in very good agreement with our measured reflectivity data.

1.1.1 MCP X-ray Optics Technology/Status

Over the past funding period, our research plan included several objectives: 1) to obtain planar square pore MCP's from two MCP manufacturers, 2) modify our existing x-ray facility with a high precession rotary table for performing basic reflectivity measurements. and 3) create a x-ray ray trace software system that would allow us to model our laboratory measurements and that would be extensible to design and evaluate more complex optical geometries for a possible flight configuration.

We have obtained several square pore MCP's from two vendors, Phillips-Mullard and Galileo Electro Optics Corp. This MCP has a L/D ratio of 40:1 with a pore size of 80μ (100μ center-to-center spacing) and an open area ratio of $\approx 70\%$. Both manufacturers (Phillips and Galileo) have demonstrated that the square pore MCP's can be fabricated with the needed characteristics for developing a x-ray optic (such as pore alignment, deep etching (4mm thick, L/D=320:1), and slumping into spherical shapes ($R < 1$m)).

Using our AXAF and ROSAT high resolution x-ray cameras, we have obtained an images of a point-like x-ray source (finite source distance) viewed through a masked region (2x6) of a square pore MCP reflector. Initial analysis of this image clearly demonstrates the feasibility of MCP optics for soft x-rays. It is important to note that these are the highest spatially resolved images of x-rays from a MCP optic. The image data clearly resolves each of the MCP pores due to a single wall reflection. The image data is consistent with the calculated reflectivities and surface

roughness (a upper limit of $\approx$ 40A rms - private communication G. Fraser). The major source of image degradation is due to the finite source size and source-optic distance.
In order to extrapolate these laboratory measurements into a flight optic design, we have developed a rather extensive x-ray ray trace software system. We have adopted a tool based approach to modeling x-ray optical components, laboratory facilities, and various science instruments. Individual software programs emulate specific telescope functions such as the X-ray source, vacuum facility aperture plates, x-ray optics, and individual detectors. (This software is also being used in the design of the HXI telescope system.)
We have extended the modeling of the laboratory system into designing several possible telescopic optic designs. The initial modeling results are consistent with Kirkpatrick-Baez (KB) optical designs. For example, we have modeled a simple single reflection 'slumped wedge' optical system. In this model an annular ring is populated with slumped MCP segments. Each of the 12 segments have a focal length of 400cm. The central core of the PSF has a FWHM of 3-5 arcsrc, however a significant fraction ($\approx$ 50%) of the encircled energy extends out to several 10's of arcmin. Initial modeling also indicates there is a potential to extend these optics into the 10-30 keV range. It is important to note that we have investigated a *very* small number of optical configurations. This project still requires a significant amount of research to determine the if passive MCP optics can lead to a significant improvement over existing technologies. We propose to continue our research into the characterizing and modeling of these devices at a much reduced level.

1.2 MCP Detector Optimization Studies

1.2.1 MCP Readout Technology

The recent introduction of 'wide field' x-ray optical designs prompted us to investigate high resolution detectors systems that are better matched to the focal planes. For example, in the case of the AXAF mirrors, curving the detector to match the focal plane would improve the off-axis angular resolution by a factor of two. More importantly, a better match of the detector to the focal plane dramatically increases the solid angle of sky over which arcsecond imaging can be achieved. This permits more efficient use of telescope time for certain classes of observations (surveys, objective spectroscopy of dense fields, etc.), and gives better x-ray positions for serendipitous sources which greatly helps in their identification.
In an attempt to meet these requirements, we have developed a planar thin film readout device to replace our current generation of free standing cross grid charge detectors (CGCD). These devices consist of two planes of thin film wires separated by an insulating layer. These devices were prototyped in a joint venture with Bell Labs (Holmdel NJ), where the basic microfabrication processes were developed and tested. These readouts have 128 wires per plane, which corresponds to over 16,000 intersections of top and bottom plane wires, each of which must be electrically isolated.
One vendor has modified these processes to improve yield and has delivered devices from two fabrication runs. Both fabrication runs were successful in generating electrically satisfactory devices. The diced wafers are mounted to a printed circuit card with an external block of thin film resistors wirebonded to the grid. This device was assembled into a HRI camera head including MCPs and readout electronics. The initial devices had unsatisfactory imaging performance due to capacitive coupling between the top and bottom wire planes. The second fabrication run produced devices with a five-fold increased spacing between the two wire planes. This enhanced the image performance significantly. However, there still exists a measurable coupling between

the two planes that prevents the grid to obtain it's ultimate imaging performance.. Due to lack of funding, completion of the project remains on hold. We plan to continue development of these devices. The ultimate goal is to replace the current generation of free standing wire grid readout devices. The processes we have developed are extensible to large readout devices (30x30cm). These devices are more robust than the standard CGCD readout, and they will also provide a substantial reduction in cost, weight, and complexity in our MCP readout system.
In the interim, we have applied the thin film technology approach to the AXAF HRC-S (spectrometer) detector. A hybrid device using a thin film bottom plane MCP readout was constructed. This device allows the segmented readout to follow the roland circle.
We are investigating the possibility of producing curved readout devices based on the technology derived from the planar thin film readout discussed above. The curved readout device would be less limited by the spatial distortions caused by the spreading of the MCP exit charge cloud. The selection of our current vendor was based in part in their ability to extend the planar lithographic technology to large area (30cm dia) curved substrates. Also, these curved readouts have implications in high resolution dispersive spectrometer systems. We propose to continue our research into the fabrication of these readout devices as part of the HXI detector program.

1.2.2 Advanced MCP Technology

With the addition of a x-ray photocathode, MCP QE can be improved significantly. Over the past SR&T funding period, we have continued our work in optimizing soft xray photocathodes. We have developed deposition techniques that allow us to evaporate several photocathode materials on a single MCP. The test photocathode materials are deposited in quadrants. This allows detailed quantum efficiencies measurements as a function of energy, angle, and deposition parameters on all four areas simultaneously so that relative effects are accurately measured. We have produced a quadrant coated MCP (Bare, CsI, CsBr, CsI+CsBr), and measured its characteristics at selected energies.
Since the initial QE measurements were made, we have modified the X-ray vacuum system to include an insertable low energy transmission grating. The addition of this monochrometer allows us to extend the existing work to include detailed QE measurements as a function of many energies and angles. These additional QE measurements at or near the absorption edges of the photocathode are critical in calculation of the effective area of a telescope system.
We have successfully investigated techniques to reduce the diffuse background components in x-ray MCP based detectors. For deep exposures ($> 10,000 sec$), diffuse, low contrast spatial and temporal background features had been observed. This anomalous background would have prevented accurate astronomical deep exposure observations. We developed electrostatic shielding techniques and an improved MCP holder design that removed these anomalous background components. The MCP based ROSAT HRI detector used these techniques to eliminate structured background observed during ground test and calibration.